Davis

February 1988 TP8856E

ALTERNATIVE LEVEL CROSSING WARNING SIGNALS FOR INCREASED VISUAL CONSPICUITY:

An Investigation of Designs Using High-Brightness Light Emitting Diodes

Prepared for the
Transportation Development Centre, Transport Canada

CA1
DTC 800
88
A44
c.2

89-04056/

Date Due

SEP 5 1989

BRODART, INC. Cat. No. 23 233 Printed in U.S.A.

CA1
DTC 800
88
A44
C2

February 1988 TP8856E

ALTERNATIVE LEVEL CROSSING WARNING SIGNALS FOR INCREASED VISUAL CONSPICUITY:

An Investigation of Designs Using High-Brightness Light Emitting Diodes

Prepared for the
Transportation Development Centre, Transport Canada

by

Brian W. Tansley

Department of Psychology
and
Systems and Computer Engineering
Carleton University

on behalf of

Davis Engineering Limited
Consulting Engineers
Ottawa, Ontario

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
DEC 13 1988
Transport Canada / Transports Canada

Davis File No.: C86-144

February 1988

31798 7

The contents of this report reflect the views of W.R. Davis Engineering Limited and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce document est inclus avant la table des matières.

Transport Canada / Transports Canada

Development / Développement

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 8856E	6719/20	

4. Title and Subtitle

ALTERNATIVE LEVEL CROSSING WARNING SIGNALS FOR INCREASED VISUAL CONSPICUITY: An Investigation of Designs Using High-Brightness Light Emitting Diodes

5. Report Date: February 1988

6. Performing Organization Report No.: 86-144

7. Author(s)

Brian W. Tansley

8. Transport Canada File No.: D1465-378-4

9. Performing Organization Name and Address

W.R. Davis Engineering Limited
1260 Old Innes Road
Ottawa, Ontario
K1B 3V3

10. DSS File No.: 11SD.T8200-6-6515A

11. DSS or Transport Canada Contract No.: T8200-6-6515/01-SD

12. Sponsoring Agency Name and Address

Transportation Development Centre (TDC)
200 Blvd. René-Lévesque West
Suite 601, West Tower
Montreal, Quebec H2Z 1X4

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. TDC Project Officer: W.G. Rowan

17. Abstract

This report documents an investigation of alternative level crossing warning signals using high-brightness light emitting diodes (LED) for increased visual conspicuity.

Experiments were carried to compare the visibility (detection threshold of various flash rates viewed against four backgrounds - daytime, nightime, with and without visual noise . The conventional signal frequency ($1 Hz$) was found to be more difficult to detect in the presence of background visual noise than the signals of slightly higher frequency.

A second set of experiments compared the visibility of five modulation rates by measuring the reaction times of 25 observers in a simulated driving environment. Results showed that average reaction times for the various signal patterns did not significantly differ from one another.

Findings suggest that novel warning signals could be developed from a range of stimulus modulation frequencies that are, themselves, not significantly different from the conventional signal with respect to detectability and range. The range of frequencies between 0.5 and 8 Hz could be used as building blocks for such signals without reducing conventional visibility.

18. Key Words	19. Distribution Statement
Grade crossing, LED signals, railway safety, conspicuity, railroad signalling	A limited number of copies of the report are available upon request from the Transportation Development Centre.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price

TDC/CDT 79-005
Rev 86

Canada

Transports Canada / Transport Canada
Développement / Development

FORMULE DOCUMENTAIRE DU RAPPORT

1	N° du rapport Transports Canada	2	N° de l'étude — CDT	3	N° de catalogue du destinataire
	TP 8856E		6719/20		

4	Titre et sous-titre	5	Date du rapport
	ALTERNATIVE LEVEL CROSSING WARNING SIGNALS FOR INCREASED VISUAL CONSPICUITY: An Investigation of Designs Using High-Brightness Light Emitting Diodes		Février 1988
		6	N° du rapport de l'organisme executant: 86-144
7	Auteur(s)	8	N° de dossier Transports Canada
	Brian W. Tansley		D1465-378-4
9	Nom et adresse de l'organisme executant	10	N° de dossier — ASC
	W.R. Davis Engineering Limited 1260 Old Innes Road Ottawa (Ontario) K1B 3V3		11SD.T8200-6-6515A
		11	N° de contrat — ASC ou Transports Canada: T8200-6-6515/01-SD
12	Nom et adresse de l'organisme parrain	13	Genre de rapport et période visée
	Centre de développement des transports (CDT) 200 ouest, boul. René-Lévesque, Suite 601, tour ouest Montréal (Québec) H2Z 1X4		
		14	Code de l'organisme parrain
15	Remarques additionnelles	16	Agent de projet — CDT: W.G. Rowan

17 Résumé

Ce rapport rend compte de la recherche faite sur différents types de feux de signalisation à diodes électroluminescentes pour la protection des passages à niveau et permettant une visibilité accrue.

Des expérimentations ont été faites pour comparer la visibilité (seuil de détection) de ces feux à des cadences de modulation variées, sur quatre types de fonds contrastants: de jour, de nuit, avec et sans bruit optique de fond. Il a été constaté que le signal clignotant à 1 Hz de fréquence était plus difficile à détecter que les signaux de fréquences légèrement plus élevées lorsqu'il y a un bruit optique de fond.

Dans une autre série d'expérimentations, la visibilité des feux à cinq cadences de modulation différentes a été comparée sur la base des temps de réponse de 25 observateurs, dans un contexte de conduite simulée. Les résultats ont montré que la moyenne des temps de réponse ne varie guère d'une cadence de signaux à une autre.

Il serait possible, d'après les résultats obtenus, de mettre au point des feux de types novateurs faisant appel à une gamme de fréquences de modulation ne différant guère des feux classiques sur le plan de la portée visuelle et du seuil de détection. Il serait possible de puiser dans les frequences allant de 0,5 à 8 Hz pour obtenir les signaux recherchés, sans pour autant réduire leur visibilité par rapport aux feux classiques.

18. Mots-clés	19. Diffusion
Passage à niveau, feux à DEL, sécurité ferroviaire, visibilité, signalisation ferroviaire	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non classifié	non classifiée		--

Canada

EXECUTIVE SUMMARY

Light emitting diodes offer a number of advantages over conventional tungsten lamps in the design of level crossing warning signals, such as light weight, long operational lifetime, low operational cost and flexible design capabilities. Their use also offers the promise of more conspicuous signals. This is because their luminance profile over time can be made complex owing to their rapid frequency response.

Existing specifications for level crossing warning lights require that their flash rates fall in the range between 30 and 45 flashes per minute with the two signals aimed down each roadway being activated in antiphase. We compared a number of alternative flash rates and patterns with this range. These included prototype signals with the potential to be more visually conspicuous as viewed against the most common types of background found in the daytime and nighttime environments. Four types of background were used: daytime and nighttime backgrounds with and without visual noise.

An experiment was carried out with three observers to compare various flash rates (0.5, 1, 2, 4, 8 and 16 Hz) with respect to their visibility. Visibility was defined in terms of the detection threshold - that is, the minimum amount of light necessary to correctly detect the presence of the signal. It was found that the detection threshold varied little over a five octave range (0.5 to 8 Hz) and fell off at higher frequencies. The conventional signal frequency (1Hz) was found to be more difficult to detect in the presence of visual background noise than signals of slightly higher frequencies.

In a second experiment, we compared the visibility of a set of five modulation signals with respect to their simple reaction times. Twenty-five observers were tested on five different signal combinations viewed against a videotaped actual driving scene. The results of this study showed that the average reaction times for each of the conditions were not significantly different from one another.

These results suggest that novel warning signals could be developed from a range of stimulus modulation frequencies that are, themselves, not significantly different from the conventional signal with respect to detectability and range. The data reported here suggests that the range of frequencies between 0.5 and 8 Hz could be used as building blocks for such signals without reducing conventional visibility. Our informal observations of mixed modulation signals lead us to suspect that they may be more conspicuous than the conventional signals. However, it remains to be proven that this is so.

SOMMAIRE

Par rapport aux lampes au tungstène, les diodes électroluminescentes utilisées pour la protection des passages à niveau présentent plusieurs avantages: légèreté, longue durée de vie, coût d'exploitation faible, souplesse de mise en oeuvre et, peut-être aussi, une visibilité accrue. Cette dernière s'explique par la réponse en fréquence plus rapide des DEL qui autorise une distribution plus ou moins complexe des luminances dans le temps.

Les deux feux de chaque côte d'un passage à niveau doivent, selon les prescriptions en vigueur, clignoter alternativement à raison de 30 à 45 éclairs par minute. Des essais ont été faits, au cours desquels diverses cadences et séquences de modulation ont été réalisées et comparées, tout en respectant le rythme de clignotement prescrit. Parmi les feux essayés figuraient des prototypes qui permettent une visibilité accrue sur les fonds contrastants les plus divers, de jour, de nuit, avec et sans bruit optique de fond.

Lors d'expérimentation, trois observateurs ont été invités à mettre en rapport cadences de modulation (0,5, 1, 2, 4, 8 et 16 Hz) et visibilité des feux, celle-ci étant exprimée sous la forme de seuils de détection: quantité minimum de lumière nécessaire pour pouvoir détecter sans erreur la présence d'un signal lumineux. Il a été constaté que le seuil de détection ne variait guère dans la gamme des cinq fréquences allant de 0,5 à 8 Hz et qu'il décroît rapidement, au-delà. Il a été constaté en outre que le signal à 1 Hz de fréquence était plus difficile à détecter que les signaux de fréquences plus élevées lorsqu'il y a un bruit de fond.

Dans une autre expérimentation, la visibilité de feux modulés à cinq cadences différentes a été comparée sur la base des temps de réponse de 25 observateurs, auxquels on a présenté cinq combinaisons différentes de signaux sur un fond constitué d'une scène vidéo montrant une séquence précise de conduite automobile. Les résultats ont montré que la moyenne des temps de réponse ne varie guère d'une combinaison à l'autre.

Il serait possible, d'après les résultats obtenus, de mettre au point des feux de types novateurs faisant appel à une gamme de fréquences de modulation ne différant guère des feux classiques sur le plan de la portée visuelle et du seuil de détection. Les expérimentations dont il a été question ont montré en outre qu'il serait possible de puiser dans les fréquences allant de 0,5 à 8 Hz pour obtenir les signaux recherchés, sans pour autant réduire leur visibilité par rapport aux feux classiques. Certaines observations faites en cours d'expérimentation sur les feux à modulation mixte permettent de croire qu'ils seront probablement plus visibiles que les feux classiques, ce qui reste, bien sûr, à prouver.

TABLE OF CONTENTS

INTRODUCTION 1

STEPS TOWARDS DESIGNING FOR CONSPICUITY 11

APPARATUS 13

EXPERIMENT 1 18

- DISCUSSION 24

EXPERIMENT 2 25

- DISCUSSION 33

BIBLIOGRAPHY 34

Introduction

"The present flashing light signal was a composite of the ideas of the members of the committee. An effort was made to patent it, in order that it might be dedicated to the A.R.A. but this could not be done. Then an effort was made to copyright it; this also failed. The question then arose as to the infringement of the Brach patent for a series of lights flashing one after the other, or giving the appearance of a swinging light. The inventor, L.S. Brach, offered to dedicate his patents to the Association. This could not be done. He then served notice that for this particular signal his patents would not be enforced. Therefore, except for the glare of phantom light suppression devices used by some roads, this signal can be purchased and installed free of any patent entanglements."

--Alexander Holly Rudd, 1936

Visual warning signals have been in use at railway level crossings since the advent of railroads. In spite of various technological refinements in the signal producing hardware introduced over the the past hundred years, the functional properties of today's level crossing signals are largely based upon specifications extant then.

The purpose of this technical report is to document our preliminary investigations into the development of visual signals specifically designed to be conspicuous to the driver of a motor vehicle travelling a roadway that approaches a level crossing. Whether this work leads to the development of a more conspicuous signal is, at present, open to question. While we have specifically set out to design a conspicuous signal, considerably more pilot work, including field tests of some prototypes, will have to be carried out before being able to answer this crucial question.

Over fifty years ago Rudd outlined some of the difficulties that the then American Railroad Association (now the American Association of Railroads) encountered in its attempt to standardize level crossing warning signals among its member railroads

(Brignano and McCullough, 1981). It is as important today as it was then to provide the driving public with an unambiguous visual warning signal regarding the approach of a train at a level crossing. The importance of maintaining safe level crossings is underlined by the fact that, while there has been a four-fold decrease in the number of fatalities at public railroad crossings since 1930, over one half of all present day railway-related fatalities occur at such crossings (U.S. Department of Transportation, Federal Railroad Administration, 1985). The problem of level crossing safety remains at the forefront among today's concerns over railroad safety--just as it apparently did when Rudd and his colleagues struggled to overcome the technological and legal limitations of their time.

The physical isolation of the railroad from the vehicle road surface is a guaranteed solution to the problem of automotive and pedestrian safety at level crossings. However, the very real financial constraints imposed by this solution make the search for improvements in level crossing visual and auditory warning signals worthwhile.

The present-day standard North American railway level crossing warning signal consists of a reflective crossbuck sign below which is mounted a pair of tungsten incandescent lamp sources with accompanying optics and red filters. These are mounted in protective housings spaced apart horizontally by 76 cm at a height of 2.8 metres above the road crown. When activated these two sources are alternately turned on and off at the rate of about 30 to 50 light pulses per minute, with a duty cycle of 50%. Thus, when the track circuit is closed the warning signal that appears is of a pair of red lights, spaced horizontally apart, flashing in antiphase. One pair of signals is shone along each of the roadway directions from the point of intersection with the railroad track(s).

Present-day level crossing signals are electrically modulated by switching the electrical current to the lamp sources. This method offers the advantage of fewer moving parts in the signal mechanism without effecting significant increases in the operational lifetime of the tungsten lamps used. As far as the author is aware, the existing signal specification, which is established as a standard on North American railroads, is not based upon any scientific evidence suggesting that the visual warning signal characteristics are optimal for drivers' visual detection and/or recognition. Indeed, the specification appears to be based upon signal designs dependent upon technology older than the tungsten filament lamp itself. Early versions of level crossing warning signals used pulsed acetylene gas lamps as sources of light for their signals. With the advent of the electromechanical level crossing warning signal, it appears that the "standards" established by the previous technology were continued.

Alternative hardware has been proposed that is intended to increase the conspicuity of the warning signal. However, it seems to have been proposed, paradoxically, without changing the physical properties of the light modulation pattern. During the 1960's and 1970's the most promising of these alternatives appeared to be the filtered electronic flash lamp. Hopkins and Holmstrom (1976) proposed the use of xenon flash lamps at railway grade crossings. In a report summarizing research and development work with red flashing signals produced with filtered Xenon flash lamps they concluded that:

> "...analysis, laboratory measurements and field tests...strongly suggest that xenon flash lamps can be employed at railroad-highway grade crossings in a manner that can increase significantly the effectiveness with which motorists are warned of approaching trains. The primary benefit accrues through the increased alerting effectiveness and conversion efficiency associated with short-duration flashes, which in turn make possible the use of a relatively broad beam pattern. Installation of such lights as supplements to existing protection is technically simple, is economical and should not have any serious liability implications.
>
> Given the optimization of equipment and a lengthy and comprehensive test of the concept, reducing costs and power consumption through elimination of some or all of the incandescent lights may prove possible. In addition, significant improvements are possible through reduction of of the severe demands now made on cantilever structures and through simplified tailoring of the light intensity to both crossing location and ambient illumination."

In spite of the optimistic predictions made for this technology, the electronic flash lamp has not gained widespread use in this application. Little work appeared, using this technology, where alternatives to the existing standard were systematically investigated. The application in marine navigation showed that extremely brief, bright signals, though detectable at moderate to long range, were more difficult to localize than the longer flashes found in conventional incandescent technology. (This is an example of where a visual signal may have certain physical attributes that make it acceptable by one or more criteria and unacceptable by others).

By the early 1980's the advent of relatively low cost, high luminance, light emitting diodes (LEDs) made it possible to consider their use in level crossing warning signal

designs. Five main features of LEDs make their consideration as signal source elements worthwhile:

1) LEDs have a long, maintenance-free operational life
2) LEDs are easily incorporated into a variety of design applications and solid state control circuits.
3) LEDs emit narrow-band light rather than broadband light and, thus, require no spectrally selective filtering. (This means potentially fewer parts in the lamp assembly and increased safety due to their inability to show any other colour than that designed for.)
4) The rise and fall times of the LED luminous output are very short so they can be flickered at any rate desired in the design--yet they can also operate in a continuous mode--something a flash lamp cannot do.
5)The LED's modest power consumption requirements, small size and lightweight packaging requirements serve to reduce operational costs and the civil engineering costs associated with their installation.

Light emitting diode technology appears to offer many advantages over other technologies at present. While we have carried out our investigations with no particular technology in mind, LED technology offers the fewest number of design limitations.

Visual Detection, Visual Recognition and the Visual Range:

Ideally, the message sent by a level crossing warning signal should be received by the driver of oncoming vehicles at sufficient distance from the crossing so that he/she is able to plan adaptive driving behaviour. This means that the signal's message should be more than merely available to be observed within the driving environment near the level crossing it is installed to protect. The information in the warning must be rapidly and accurately processed by the drivers who are in the vicinity when the crossing warning signal is activated.

To achieve this purpose the signal must first be **detected** by drivers from among many visual stimuli that may be within their visual field. Next, the signal must be **recognized** for what it is intended to be--a visual warning indicating the approach of a train at the level crossing. A signal that has both of these properties is **conspicuous.**

Visual detection refers to the capability of an observer to discriminate the

presence of a minimum amount of light in a signal from the background upon which it is viewed. This minimum amount is referred to as the **detection threshold** and is typically taken as the **luminance contrast** necessary for observers to correctly report seeing the signal against its background on approximately one half of the trials upon which the signal is presented.

The **visual range** of a light signal is that distance between the signal and the observer at which the detection threshold is reached (i.e., where the probability of correctly stating whether the light is on when it is on is about 0.5). For lights of small angular subtense, this distance can be calculated by determining where the **luminance contrast of the signal light against its background is reduced to less than 5%.** When these conditions are met the value obtained is known as the **Meterological Optical Range.** (While 5% is somewhat larger than is typically found in laboratory settings for the detection threshold, it is used as it represents a conservative estimate of the visual range.)

The **luminance contrast, K,** is calculated as:

$$K = \Delta I / I_{background},$$

$$\text{where,} \quad \Delta I = I_{signal} - I_{background} . \qquad (1)$$

The value of K ranges from -1 (where the signal luminance is 0) through zero (where the signal and background are equal) to 1 (where the signal is twice the luminance of the background) to values significantly greater than 1 (where the signal is significantly more than twice the luminance of the background).

The luminance contrast of a signal and its background, determined in this way, does not take into account any increased visibility due to luminance fluctuations in time. Typically, it is only the peak or time-averaged luminance of the signal that is used as the measure of I_{signal}.

Using luminance contrast as the physical parameter to be optimized, the following manipulations are used to maximize the visual range of the signal:

1) The signals are placed 2.8 metres above the road surface
2) High luminance light sources are used
3) In order to maximize the luminance contrast, K, of the level crossing warning signal the light source is embedded in a black annulus. This produces a signal contrast greater

than that obtained by spatially juxtaposing the signal against the sky.

In addition to these manipulations, the signal lights are:

4) spectrally filtered so as to appear red. (The chromaticities acceptable for use in this application by the railroad is somewhat more lenient toward the short-wavelength region of the spectrum than those used in trackside signals. This has the effect of increasing the luminance of the signal which, in turn, increases the visual range of the signal.)

Finally, the lights are:

5) pulsed (that is, switched on and off) at a rate of approximately 30-45 times per minute.

Although manipulations 4) and 5) might serve to increase the signal's conspicuity, it is also true that both of these manipulations have the effect of reducing the visual range of the signal (as computed by equation 1 above). **This seemingly paradoxical statement is true because, although the visibility of a signal is defined by luminance contrast, the conspicuity of a signal is not solely dependent upon the signal's luminance contrast. Signal colour and the spatial and temporal profile of a signal's luminance distribution must also play a role in determining signal conspicuity.** This is particularly true where visually noisy backgrounds may be involved.

Given that it would be optimal to provide as much advance warning as possible to a driver regarding the approach of a train, it would seem prudent to design for maximum visual range. As defined above, this involves making the value of K as large as possible. However, practical considerations mitigate against optimal designs using high positive values of luminance contrast. The cost of producing high luminance visual signals impacts on both capital and operational budgets and in most railroads there is continual pressure to trim these budgets . This pressure results in the search for ways to reduce, rather than increase, the luminance values achievable by a signal source because increased luminance costs money.

The ergonomics of a warning signal:

Knowledge of the detection threshold of a light does not permit one to predict whether the light will be perceived by the driver. It only permits a determination of whether or

not there is sufficient light available to be above or below the visual detection threshold at a given distance.

Visual recognition refers to the ability of the driver to correctly detect various aspects or perceptual attributes of the signal, such as colour, location, shape, wording, etc. **For each signal attribute there may be a different recognition threshold.** This means that, at a given distance from the signal, different aspects or attributes of a visual signal may be above detection and or recognition threshold while others may be below. **To the extent that a given signal attribute carries the signal's message the recognition threshold for that attribute must be surpassed before a driver can be expected to act adaptively.**

For all signals where the angular subtense is small (including level crossing warning lights at moderate to long range) the detection threshold is typically lower than the recognition threshold. That is, at a given distance the driver will need less signal intensity to detect its presence than to recognize its meaning. As a person drives towards an active level crossing signal the warning light will be detected at a distance further away from the crossing than it will be recognized. (How much further away is difficult to estimate without taking specific features of the signal into consideration such as flash rate, colour, background characteristics and sky illumination.)

The role of uncertainty as to the direction of the driver's gaze:

At any given moment the driver's gaze may or may not be directed towards the level crossing. As it is important to transmit the level crossing warning signal message as soon as possible after the train activates the track circuit it is desirable make the signal as conspicuous as possible.

Visual conspicuity refers to the properties of the signal that serve to attract the driver's attention. **A conspicuous signal is one that is more likely to be detected and whose relevant attributes recognized.** The goal in designing a good level crossing signal is to provide the driver with an unambiguous message at a sufficient time/distance away from the crossing to act adaptively.

While recognizing the value in designing for conspicuity, the design of a conspicuous signal is not straightforward. First, the optimum characteristics of a conspicuous signal vary depending upon the complexity of the **visual background** (i.e., what other visual stimuli are in the driver's field of view that could be confused with the signal) and the location within the driver's own visual field in which the signal is presented.

Second, the optimum characteristics of a conspicuous signal will also depend upon the **activity background** in which the various subtasks of driving are embedded. The nature of the tasks that the driver is engaged in at the time of signal presentation can affect his/her attentional capacity which, in turn, affect visual sensitivity. This suggests that it may be appropriate to consider modifying the activity background by modifying the driving environment (e.g. altering speed limits, changing the road surface, curvature, etc.) as a means of affecting or controlling at least some of the factors that may determine the driver's readiness to accept a visual signal.

These factors make it difficult to both design for conspicuity and to assess, experimentally, designs that are intended to increase conspicuity. It is typical for estimates of the detection threshold for a given light to be determined experimentally by presenting the visual stimulus against a homogeneous background. A more useful and realistic background, however, might be one that simulates the type of background commonly found in the visual environment of the driver in which the signal is most commonly encountered. Results obtained from two such backgrounds can be very different. It is known, for example, that the detectability of brief, point sources of light is changed by the presence of a number of other point sources nearby in the visual field. This appears to be particularly true of flashing lights.

Gerathewohl (1957) found that flashing lights were generally more conspicuous than steady ones of the same luminance contrast. For low luminance contrasts he found that signal conspicuity increased with increased flash frequency, up to 3 flashes per second. His most conspicuous signal was reported to be at 3 flashes/second with a luminance contrast of 1.0 or greater. Gerathewohl reported that this finding was consistent with the work of Crumley and Atkinson (1954) who found that shorter reaction times were obtained to flash trains whose 'on' times were shorter compared to flash trains whose 'on' times were longer.

Gerathewohl (1957) interpreted both his results and the results of Crumley and Atkinson (1954) as support for the notion that the human 'response time' to a visual stimulus "may not be a simple function of stimulus intensity but also of the time after onset of the signal when the retina is maximally stimulated..." It is plausible that a combination of maximum stimulus luminance and a derivative of the temporal luminance distribution of a flash train may be necessary to predict the response times in the above-mentioned work.

Conners (1975) investigated the conspicuity of lights of small angular subtense presented to various locations in the visual field. She found that changing the intensity

of the target stimulus had a greater effect upon both detection threshold and upon simple reaction time (a measure of how fast an individual can manually or verbally respond to the presence of a signal) for steady lights than for flashing ones. She also found that there was little difference in the detection threshold as a function of stimulus modulation rate, through the 2-4 flash per second range appeared to be most effective in terms of reaction time. Her results, however, failed to confirm the monotonic relationship between flash rate and conspicuity, as reported by Gerathewohl (1954).

The effect of retinal location and target colour were also investigated. Conners (1975) found that targets presented to the near periphery (between 3 and 8 degrees eccentric to the centre of gaze) were reacted to fastest. She also reported that "red target lights were missed more frequently and responded to more slowly than lights of other hues." Given the condition under which her experiments were made, these latter results suggest that both detection and reaction times may have been mediated by the scotopic system in the retina--the system that mediates night vision.

The role of the background against which a signal is viewed is an important consideration affecting the visibility and conspicuity of flashing lights. Crawford (1962) found that shortest reaction times were obtained using flashing lights as target signals viewed against steady, homogeneous backgrounds. However, he found that the longest reaction times were obtained using flashing light target signals viewed in a noise background that included other flashing lights. He found that the reaction times increased with the number of irrelevant flashing lights in the background against which the target stimuli were viewed and that the "advantage gained by the use of a flashing light as a signal was lost if even one other light in the background was flashing" (Crawford, 1963). Crawford used a constant flash rate among all background and target stimuli--an unlikely real-world condition. This makes the extension of his findings to complex backgrounds difficult.

In spite of the apparent inconsistencies in the literature in this area trends have emerged. These are:

1) For signal contrast levels near detection threshold, it appears that flashing lights are more conspicuous than steady ones.
2) within the range of flash rates studied, the region around 2-4 Hz seems to be most conspicuous
3) The more lights in the background with stimulus properties near to those of the signal, the more difficult it is for observers to detect and recognize the signal.
4) Response times to signal detection is faster when the light is

presented in the near peripheral retina than when it is presented to either the central fovea or the far periphery.
5) Where detection is mediated by the scotopic system, long wavelength lights (normally seen as 'red' when viewed centrally) are less detectable than other lights. That is, the effective visual range of such lights, when viewed peripherally, will be shorter than when viewed centrally.

In order to be effective as signals, warning lights must be detected and recognized at appropriate times and places. Conventional practice suggests that the most important physically measurable light parameter for specifying the visibility of a light signal is the luminance contrast that the signal makes with its background.

Limits on signal visibility:

There are bounds upon the range over which a signal can theoretically be seen, independent of the activities of the observer. These limits are imposed by the curvature of the earth and by atmospheric transmissivity. When the observer is on flat terrain, the sight path to the signal is unobstructed and the atmospheric transsmissivity is high, the range at which the signal will be seen will be dependent only on two factors: the signal's luminance contrast and its elevation off the ground. The so-called **geographic range** of the signal is the distance at which the curvature of the earth blocks the propagation of light from the signal to the observer).

While these limits are easy to determine for any given situation, they are of little concern for the majority of railway level crossing applications. Under most circumstances the terrain is not flat and the atmospheric transmissivity not critically low. In the 'real world' the sight path to the signal is invariably obstructed at least some of the time and, under many, if not most, circumstances observers who fail to detect the signal do so well within the range of the signal as defined by the detection threshold.

We offer the following as a more comprehensive definition of a signal's effective range that includes the design goal:

The effective range of a visual warning signal is the maximum distance at which the signal is able to attract the attention of the driver and provide sufficient visual information for the driver to organize and

execute adaptive behaviours .

This definition recognizes the importance of visual warning signals being able to provide the driver with ***information*** s/he can use to act adaptively. (Acting adaptively is meant herein to mean that the signal makes it possible for the individual to make the safest driving decisions and to execute these decisions.)

Steps Towards Designing for Conspicuity:

In the following section we outline the steps we have taken to design a conspicuous warning signal. This design process is done under two important constraints:

1) There are existing specifications for the characteristics of level crossing warning signals. These specifications are set by legislation. Any proposed changes to the existing specification will either have to be consistent with it or new legislation will have to be put in place to permit its use (and possibly, restrict its use in other applications).

2) The design must be practically realizable--thus, it must be able to be made from available, cost-effective technology. Starting from the first principles of human vision, we developed a 'wish list' for the ideal, conspicuous visual warning signal.

1. The signal must be detectable at long, medium and short range.
The location of the driver at the onset of the signal can not be known, therefore all locations must be designed for. Depending upon the driver's direction of gaze the physical properties of the most conspicuous signal will change. This is because the anatomy and physiology of the visual pathway in humans is different in different locations in the peripheral visual field.

2. The pertinent signal attributes must be recognizable as soon as possible after detection. Given that the recognition of the warning signal's various perceptual attributes does not always accompany the detection of the presence of the signal, it is important to optimize the transmission of the message (carried in the signal's perceptual attributes) so as to make it possible for the driver to get the signal's message as close to the point of detection as possible.

3. The signal must convey an unambiguous message to the driver--one that makes it possible to act adaptively with an acceptable margin of safety. Ideally, the message should change with the degree of danger present.

Thus, our design goal was to find a signal that matched or exceeded, on each of these three

criteria, the present level crossing signal specification.

Taking the present specification as a point of departure, we investigated the physical manipulation of the warning signal most likely affect both visibility and conspicuity: varying luminance contrast with time. The human visual pathway is limited in its ability to follow extremely slow or rapid changes in luminance with time. Centered about a modulation frequency of around 7 Hz, observers require the least amount of sinusoidal luminance modulation in order to detect the presence of flicker. Other frequencies, either higher or lower than this value, require greater changes in luminance contrast in order to be detected. The loss of visual sensitivity to extremely low frequencies is not a problem here, because such frequencies are unacceptable as warning signals due to their slow rate of change. Consequently, we were only limited by the high frequency loss of sensitivity found from about 8 Hz upwards. We investigated a range of one octave steps using square wave luminance modulation --akin to mechanically switching on and off a visual signal source. We bracketed the present specification: going from from 0.5 Hz to 16 Hz.

Visually noisy backgrounds:

In order to attempt to assess these manipulations under realistic visual conditions we used visually noisy backgrounds. These backgrounds were designed to simulate the temporal and spatial characteristics commonly found in the nighttime visual driving environment and during worst-case daytime environments such as fog and blowing snow.

We used two conventional psychophysical measures in our investigations to compare among various signals:

1) the **detection threshold** or miminum luminance contrast necessary to correctly identify whether or not the signal was present during a fixed observation interval (independent of its suprathreshold perceptual attributes)

and

2) **simple reaction time** (the amount of time necessary to detect, recognize and respond to the signal as a function of its luminous intensity).

The detection threshold data were obtained using a 'criterion free' forced choice method known as PEST (Parameter Estimation by Sequential Testing, (Taylor and Creelman, 1967)). The reaction time data were obtained using a randomized trials

method where the exact location and position in time of the warning signals was unknown from trial to trial.

Apparatus:

Both methods were automated and controlled by a microcomputer system interfaced to the visual display tachistoscope. Figure1 shows a schematic diagram of the custom made, three channel tachistoscope used in these experiments. Each of three frontoparallel planes, perpendicular to the observer's field of view were optically superimposed at the observer's eye from a distance of 2 metres. (This distance was chosen because of the finding that, in the absence of an adequate stimulus to accommodate to, the resting focus of the average adult eye is 0.5 dioptres, corresponding to a focal length of 2 metres (Liebowitz, Owens and Post, 1982). Thus, the likelihood of our results being affected by failure to hold optimal accommodation would be minimized, if not eliminated.)

The observer's head was fixed in place with the use of a bite bar arrangement and his/her eye position was monitored with an infrared video camera and infrared illuminator to an accuracy of 0.5 degrees of visual angle. The experimental apparatus made it possible to present the stimuli only when the eye's fixation was within acceptable limits (typically +/- 1 degree).

Channel 1 contained the target or signal stimuli. These were generated by two high-brightness light emitting diodes whose outer plastic cases were milled flat on one side in order permit their being spatially juxtaposed. The two were press fit into an aluminum block which was mounted on a microscope translation stage at the end of the channel lane, 2 metres from the observer's eye. The translation stage made it possible to precisely locate the two LED targets in the field of view. The entire field subtended a visual angle of +/- 25 degrees about the point of fixation in both the vertical and horizontal directions. The visual angle subtended by the intertarget distance at 2 metres was made equal to that subtended by a level crossing warning light pair at approximately 0.5 miles (1.25 millimetres to subtend a visual angle of 3 min.).

Each of the two signal LEDs were placed behind a 100μ pinhole in order to render their images as point sources. The luminous output of each LED was independently controlled from a programmable, 12-bit digital to analog converter interfaced to a microcomputer.

The relationship between the impressed voltage to the LEDs and their luminous

outputs were calibrated prior to the experiment.

This was done by applying a constant voltage to each of the LEDs in turn and measuring the luminous output with a Prichard Photometer from the point of the eye of the observer in the apparatus.

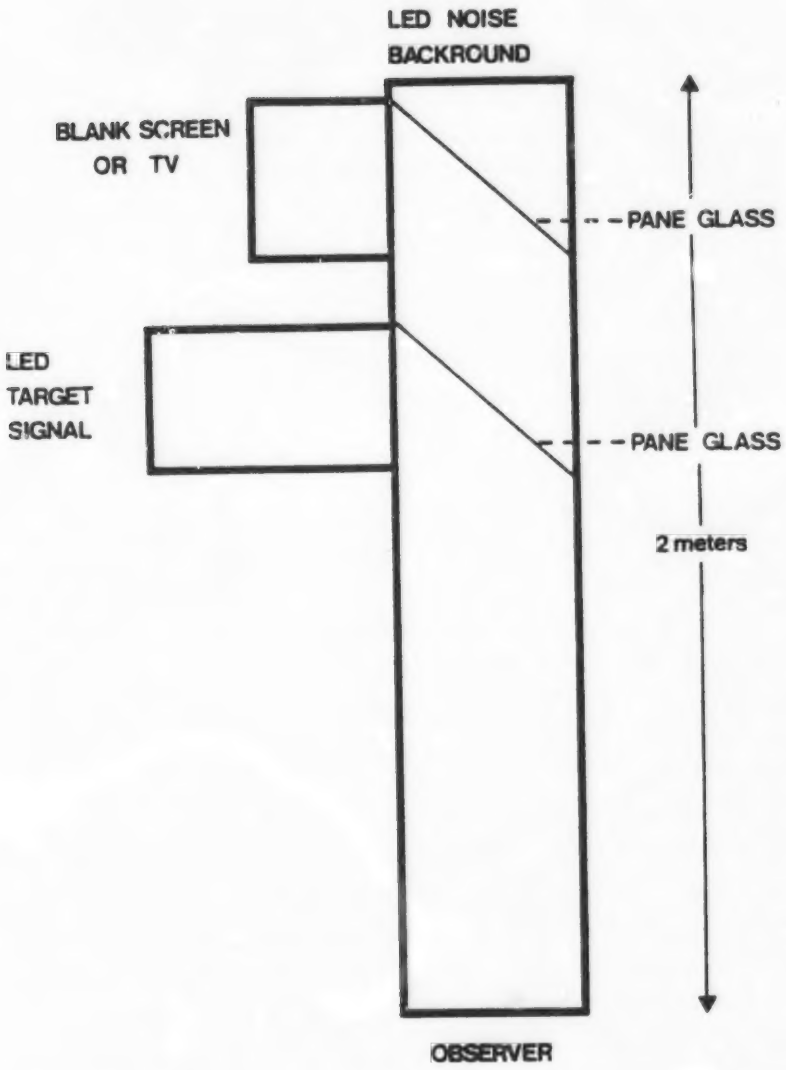


Figure 1: Schematic Layout of the Tachistoscope Apparatus

The linearity of the voltage to luminance relationship for each LED and the equality of outputs of the two LEDs for each luminous step in the voltange/luminance relationship during the experiment was maintained by reference to a set of lookup tables stored in memory.

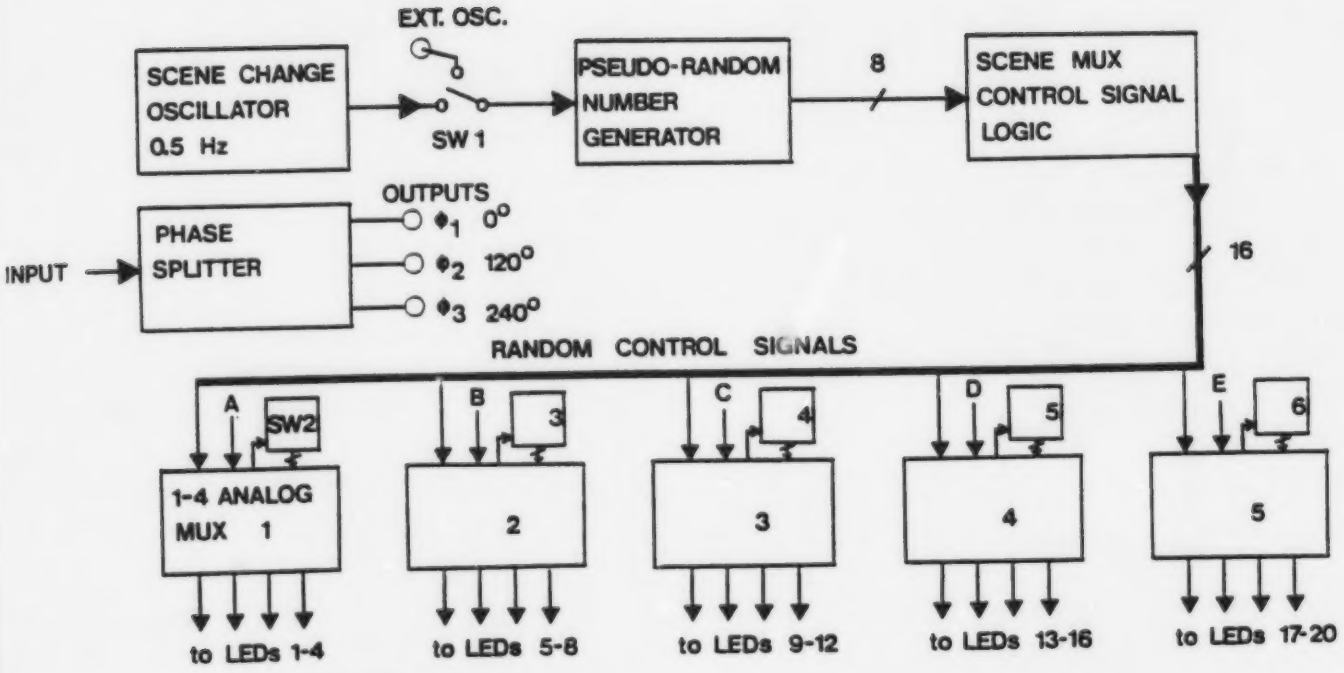
Channel 2 contained the noisy background field, which consisted of 20 LEDs of which approximately one half were yellow and one half red. These diodes were controlled by the device schematized in Figure 2. This device made it possible to produce quasirandom luminance modulation of the background LEDs. We used it to approximate background stimulus conditions described by Crawford (1962) and a variety of other background noise configurations.

These visual noise backgrounds ran independently of the visual signal channel. This was achieved by the use of programmable logic that generated a series of 'scenes'--each with independently specifiable statistical properties with respect to the 'on' or 'off' status of each LED.

A pseudo-random number generator was used to control which subpopulation of the 20 LEDs was enabled in any one scene. The pseudo-random number generator was externally triggered by a 'scene change oscillator' set to trigger a new 'scene' every two seconds. Within a given scene each of the subpopulation of LEDs could be externally modulated by an AC signal from an external source in one of three phases (0, 120, 240 degrees). In this way the background array of yellow and red lights could be changed to include new modulation rates and positions--in an unpredictable manner.

We tried to simulate the type of spatial and temporal patterns of point sources encountered in actual driving conditions. In the absence of a proper driving simulator (with motor tasks relevant to the driving scene) we chose to try to simulate the visual task of detection and measure responses to the presentation of the various signals to be compared. Both red and yellow LEDs were used. An informal analysis of the night time visual driving conditions suggested that the maximum flash rates encountered, except for emergency vehicle warning lights, was less than 2 Hz. (This includes steady lights that are 'flashed' at the observer while driving by and being temporarily occluded by other vehicles, lamp posts, advertising signs, buildings, etc.).

We chose to assess the effect of changing the warning signal temporal profile upon detection threshold at two adaptation levels (simulating both daytime and nighttime driving conditions). These were achieved through the use of a steady background that



RANDOM DISTRACTOR SYSTEM BLOCK DIAGRAM

Fig. 2

was uniformly illuminated by a back projector. In any given trial the noise background contained a series of four noise 'scenes' --each consisting of 5-7 yellow and red LEDs clustered in a 'shotgun' pattern about the central fixation point.

The LEDs in each scene were flashed at temporal modulation rates ranging from 0.25 Hz to 2 Hz and a new scene was switched into view once every five seconds. The frame sequence was random with the constraint that no frame would repeat itself in successive intervals and that no noise signals would be present within 0.5 degrees of the signal LEDs. The noise pattern appeared random with respect to colour, flash rate and position of lights in the cluster about fixation.

For the detection threshold determinations the visual field also contained a pair of **fixation lights**, spaced vertically apart by 2 degrees (presented in channel 2 of the tachistoscope). Observers were assisted in finding this location through the use of fixation lights. The target stimuli were presented equidistant between the fixation lights.

For the **reaction time experiments** the visual noise background was replaced with a video taped winter scene shot from the driver's perspective in an automobile travelling approximately 60 km/h down a straight stretch of country road. The warning signals were optically superimposed upon this scene in the most likely location within the scene where such signals would be found-- 3 to 5 minutes above the horizon and slightly to the right of the horizon and roadway.

Visibility estimates obtained from the scene scale showed that the horizon and road surface intersected at approximately one mile in clear weather. Therefore, in experiment 2 the observer had information from the driving scene as to the most likely signal location. No other fixation aids were presented

Experiment 1: ***Relative comparison of detection thresholds for inphase and antiphase signal pairs presented in a visually noisy background***

In the first experiment estimates were made of the detection threshold for both inphase and antiphase signal pairs using an adaptive, criterion free psychophysical procedure known as the "P.E.S.T." algorithm (Taylor and Creelman, 1967). Because of the extended periods of time needed to complete this experiment, only three paid observers participated. Each was pretested for colour vision and visual acuity and found to be within normal limits. Each observer contributed approximately 25 experimental sessions to the study. Each experimental session consisted of about one hour's

observeration time. Before the observations were made, the subjects were comfortably seated and dark adapted for approximately 20 minutes.

Procedure:

Each experimental session contained a series of trials--each consisting of an auditory warning tone followed by two, three second observation intervals, separated by another, distinctive auditory warning tone. The subject's task was to determine in which of the two intervals the visual signal was presented and to respond by pressing one of two response buttons within a two second period. The P.E.S.T. algorithm uses information about previous responses to determine the next stimulus step size and direction (i.e., smaller or larger step, increase or decrease in luminance).

The P.E.S.T. algorithm has been shown to generate threshold data that are optimal--that is, as good as can be statistically expected given the arbitrary level of accuracy specified in advance by the experimenter.

In the detection studies of experiment 1 the minimum stimulus intensity necessary to detect the presence of the target signals (but not necessarily recognize their colour or their flash rate) was determined for six modulation frequencies (.5, 1, 2, 4, 8 and 16 Hz)
upon backgrounds of two average luminances (0 cd/m^2 and 300 cd/m^2) and two levels of background distractor 'noise' (see apparatus section, above, for details):

1) simulated nighttime adaptation conditions with noise background
2) simulated daytime adaptation conditions with noise background
3) same as (1) but without noise background
4) same as (2) but without noise background

Results:

Figures 3(a-d) summarize the results of Experiment 1. In these figures the minimum luminance necessary to detect the presence of the LED warning target upon the various backgrounds is plotted as a function of the various signal pulse rates (0.5, 1,2,4,8 and 16 Hz). In each panel the open squares show the condition where the two signal lights were modulated inphase while the closed diamonds shows the condition where the two signal lights were modulated in antiphase.

Figure 3(a) shows the detection threshold estimated by the PEST algorithm for these

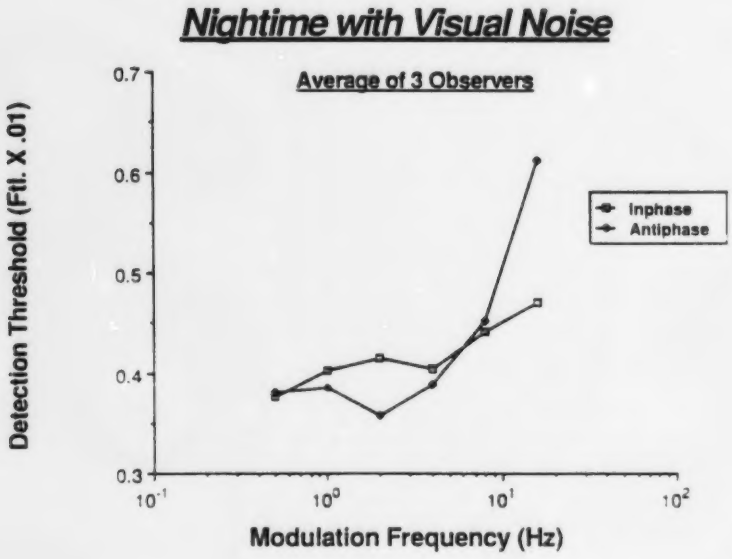

Nightime with Visual Noise
Average of 3 Observers
Detection Threshold (Ftl. X .01)
0.7
0.6
0.5
0.4
0.3
Inphase
Antiphase
10^{-1}
10^{0}
10^{1}
10^{2}
Modulation Frequency (Hz)

Fig. 3a

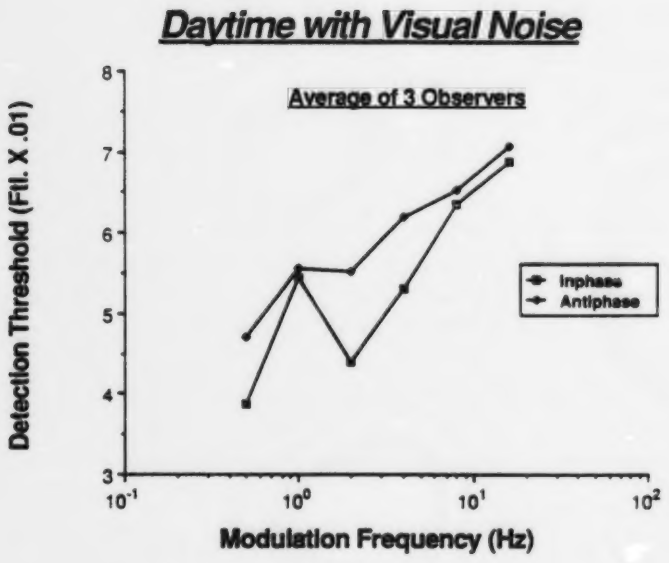

Daytime with Visual Noise
Average of 3 Observers
Detection Threshold (Ftl. X .01)
8
7
6
5
4
3
Inphase
Antiphase
10^{-1}
10^{0}
10^{1}
10^{2}
Modulation Frequency (Hz)

Fig. 3b

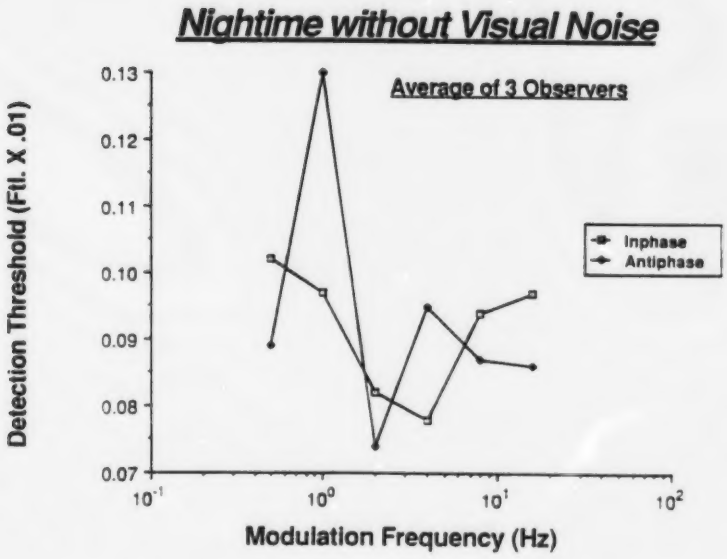

Nightime without Visual Noise
Average of 3 Observers
Detection Threshold (Ftl. X .01)
0.13
0.12
0.11
0.10
0.09
0.08
0.07
Inphase
Antiphase
10^{-1}
10^{0}
10^{1}
10^{2}
Modulation Frequency (Hz)

Fig. 3c

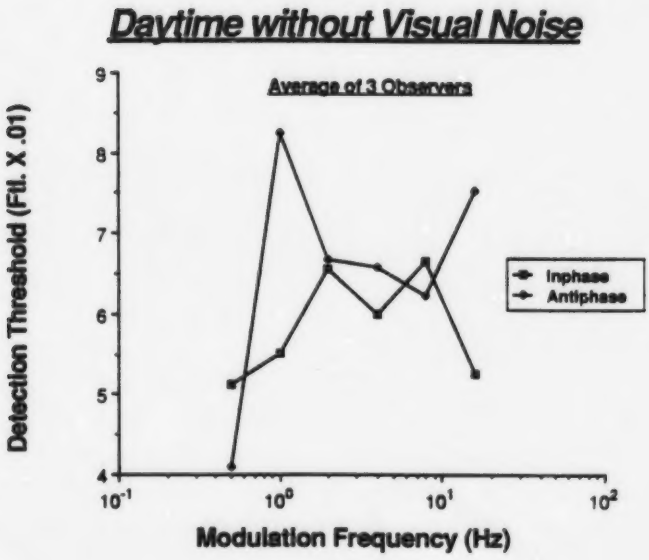

Daytime without Visual Noise
Average of 3 Observers
Detection Threshold (Ftl. X .01)
9
8
7
6
5
4
Inphase
Antiphase
10^{-1}
10^{0}
10^{1}
10^{2}
Modulation Frequency (Hz)

Fig. 3d

Table 1

LED Modulation Detection Threshold (Ftl. X .01)

Subject 1

Modulation Frequency (Hz)	Nightime		Nightime + Distractors		Daylight		Daylight + Distractors	
	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase
0.5	0.107	0.086	0.433	0.443	6.530	5.280	3.690	5.440
1	0.100	0.106	0.469	0.464	6.560	5.060	5.910	5.880
2	0.098	0.070	0.476	0.397	6.940	4.690	4.200	5.140
4	0.098	0.098	0.423	0.427	5.060	5.440	5.160	6.190
8	0.102	0.113	0.521	0.562	4.310	4.310	6.760	6.280
16	0.102	0.088	0.522	0.728	4.690	6.940	7.230	7.620

Subject 2

Modulation Frequency (Hz)	Nightime		Nightime + Distractors		Daylight		Daylight + Distractors	
	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase
0.5	0.090	0.096	0.339	0.301	4.560	3.810	4.830	4.580
1	0.099	0.102	0.372	0.301	6.440	6.640	3.980	4.530
2	0.080	0.070	0.299	0.224	5.400	6.540	3.970	5.790
4	0.039	0.083	0.337	0.333	4.480	5.490	5.710	6.540
8	0.080	0.061	0.397	0.386	5.720	5.930	6.670	6.670
16	0.086	0.080	0.442	0.498	4.400	6.330	7.030	7.230

Table 1 cont'd

LED Modulation Detection Threshold (Ftl. X .01)

Subject 3

Modulation Frequency (Hz)	Nightime		Nightime + Distractors		Daylight		Daylight + Distractors	
	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase
0.5	0.108	0.086	0.357	0.395	4.310	3.190	3.090	4.090
1	0.092	0.182	0.368	0.394	3.560	13.060	6.440	6.260
2	0.069	0.083	0.466	0.451	7.310	8.810	5.030	5.620
4	0.096	0.103	0.451	0.406	8.440	8.810	5.060	5.840
8	0.099	0.088	0.406	0.409	9.940	8.440	5.620	6.630
16	0.104	0.089	0.448	0.606	6.690	9.310	6.380	6.340

Average of Three Observers

Modulation Frequency (Hz)	Nightime		Nightime + Distractors		Daylight		Daylight + Distractors	
	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase	Inphase	Antiphase
0.5	0.102	0.089	0.376	0.380	5.133	4.093	3.870	4.703
1	0.097	0.130	0.403	0.386	5.520	8.253	5.443	5.557
2	0.082	0.074	0.414	0.357	6.550	6.680	4.400	5.517
4	0.078	0.095	0.404	0.389	5.993	6.580	5.310	6.190
8	0.094	0.087	0.441	0.452	6.657	6.227	6.350	6.527
16	0.097	0.086	0.471	0.611	5.260	7.527	6.880	7.063

signals as viewed by a dark-adapted eye against a nighttime scene with visual noise present in the field. Figure 3(b) shows the same functions viewed with a light adapted eye, obtained against a daytime scene with visual noise. Figures 3(c) and 3(d) show the nighttime and daytime adaptation data obtained without visual noise in the background field.

Discussion:

In the absence of visual noise and for frequencies around 1 Hz, the antiphase conditions appear to be more variable than the inphase conditions. At detection threshold the inphase modulation of the signal lights appears to generate more systematic data than does antiphase modulation. Table 1 provides a numerical summary of these data.

A notable difference among these panels is found between the conditions with and without visual noise. The data obtained in the presence of visual noise show the characteristic fall-off in sesitivity with increased modulation frequency. In the dark-adapted condition (Figure 3(a)) the absolute sensitivity is reduced fourfold by the addition of our visual noise scene. However, the shape of the function becomes more systematic. The function also becomes more systematic in the presence of visual noise in the light adapted condition (Figure 3(b)).

The region around 1Hz appears to be more variable for the antiphase condition than for the inphase condition. In our opinion, the most likely explanation for this difference is due to the nature of inphase and antiphase stimulation of the retina. In the inphase condition there is twice the absolute amount of light light available in the peak of the temporal luminance profile.

If one considers the spatial relationship between the two signal lights at long range in the context of the eye of the observer, then they fall on nearly the same part of the retina. Thus, they are spatially fused, and can be regarded as a single source for long range viewing. If this is true then there is 100% modulation of the visual stimulus in the antiphase condition --while there is effectively 0% modulation of the visual stimulus in the antiphase condition. (The latter is true because as the left signal is going off, the right signal is coming on and vice versa. Thus, the first derivative of luminance with respect to time is zero.)

Experiment 2: ***Relative comparison of 'simple reaction times' for inphase and antiphase signal pairs presented in a simulated driving environment.***

In an attempt to make a more direct connection between the driving behavioural subtasks and the visual conspicuity of our signals, we carried out a series of experiments using simple reaction time as our dependent measure. Simple reaction time is defined as the reaction time taken to respond without the added requirement of decision making. Thus, the observers in this study were required only to press a button as soon as they saw the warning signal light.

Procedure:

The warning signal targets were presented in various combinations of spatial phase and stimulus intensity against a background video recording of a real driving scene (see apparatus section for more details). The condition was chosen to represent a moderate level of distraction for the observer. As with experiment 1, a given experimental trial was initiated following an auditory warning tone.

The observer' task was to press a button with his/her right hand as soon as a visual signal was detected. After the warning tone a variable period of time elapsed in each trial until the visual warning signal was presented. **Simple reaction time** was taken as the time from the onset of the visual signal until the button was pressed by the observer.

Twenty-five subjects participated in this experiment. Each was tested for visual acuity and found to be within acceptable limits for obtaining a vehicle operator's licence in the province of Ontario.

Five stimulus conditions were presented over the course of the experiment. These were:

1) 0.5 Hz antiphase (the conventional signal)
2) 3 Hz inphase
3) 3 Hz antiphase
4) 5 Hz inphase
5) a 'mixed modulation' stimulus, consisting of segments of each of the first four in a sequence shown in Figure 4, below.

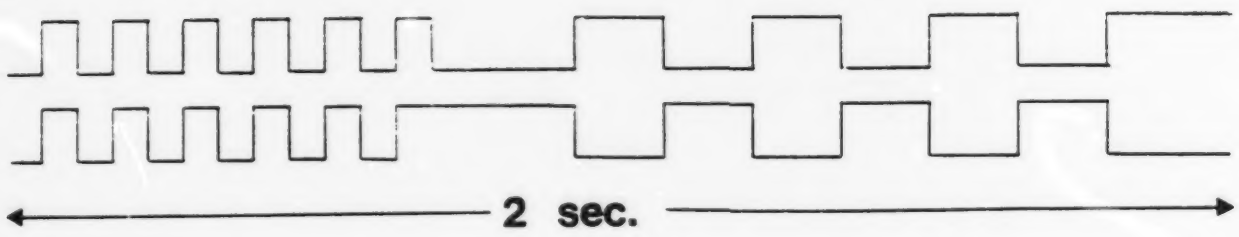


FIGURE 4 MIXED MODULATION PATTERN

Each of these stimulus conditions was presented at six discrete signal luminance levels, ranging from 350 cd/m^2 to 70 cd/m^2. In combination with the light from the driving scene background, these signal levels produced six contrast ratios that made the visibility of the signal range from very near the detection threshold to well above the detection threshold defined in Experiment 1,

Results:

Figure 5 (a-e) shows the simple reaction time data obtained for each of the five temporal luminance profiles described above. Each data point is the average of 25 observers. Each observer was presented with each stimulus condition 10 times.

Reaction times range from a minimum of 350 milliseconds, where the stimulus was well above threshold at the moment of stimulus onset, to a maximum of 1500 milliseconds, where the stimulus was near detection threshold against the driving scene upon which it was presented.

All the data show that simple reaction time is a negatively accelerating function of stimulus luminance. Although the signals are readily visible beyond about the second data point from the left hand side of the graph, the reaction times do not increase in linear proportion to the log of stimulus luminance. This relationship is mitigated by the limits to human motor response towards the right hand side of the graph. Table 2 provides a numerical summary of these data.

	LED INTENSITY (foot-lamberts)					
SIGNAL	20	35	45	60	80	100
0.5 Hz. anti-phase	1.13	0.50	0.42	0.40	0.36	0.34
3 Hz. in-phase	1.11	0.6	0.47	0.41	0.41	0.4
3 Hz. anti-phase	1.31	0.62	0.47	0.44	0.4	0.37
5 Hz. in-phase	1.26	0.6	0.51	0.43	0.4	0.39
enhanced conspicuity signal	1.54	0.62	0.52	0.42	0.37	0.38

Values are the averages of the reaction times for twenty five (25) subjects. (seconds)

TABLE 2

RESULTS OF REACTION TIME TESTING

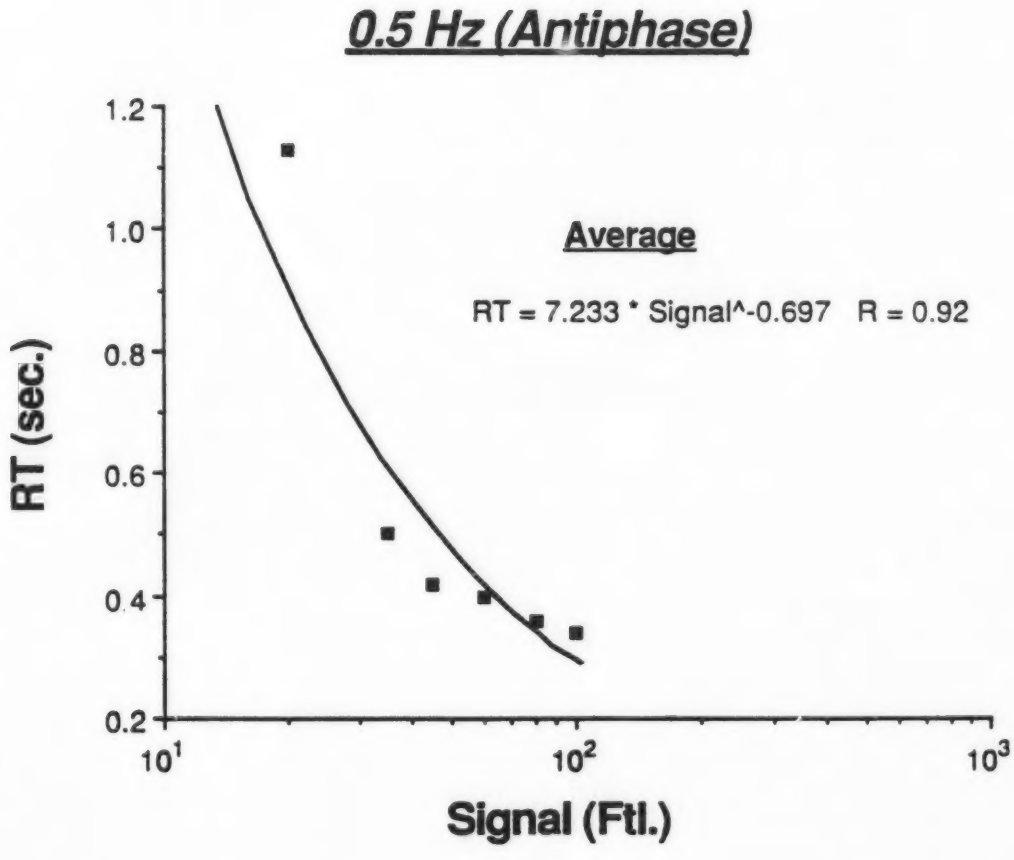

0.5 Hz (Antiphase)
Average
RT = 7.233 * Signal^-0.697 R = 0.92
RT (sec.)
1.2
1.0
0.8
0.6
0.4
0.2
10^1
10^2
10^3
Signal (Ftl.)

Fig. 5a

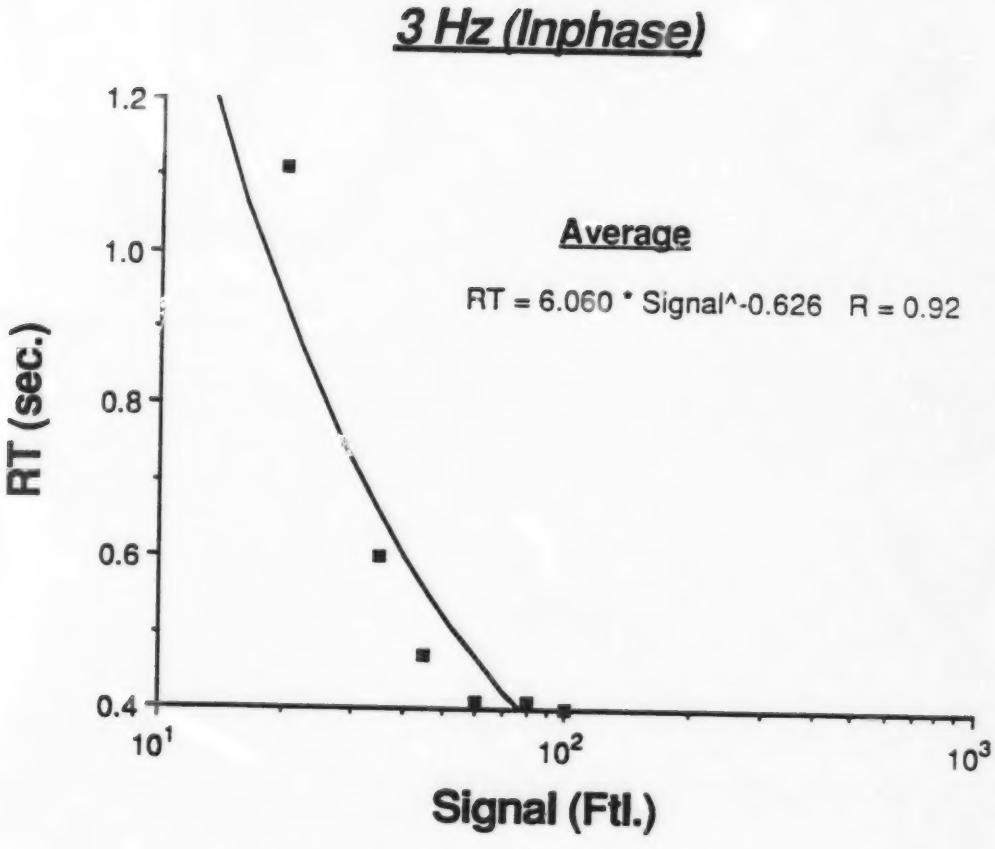

3 Hz (Inphase)
Average
RT = 6.060 * Signal^-0.626 R = 0.92
RT (sec.)
1.2
1.0
0.8
0.6
0.4
10^1
10^2
10^3
Signal (Ftl.)

Fig. 5b

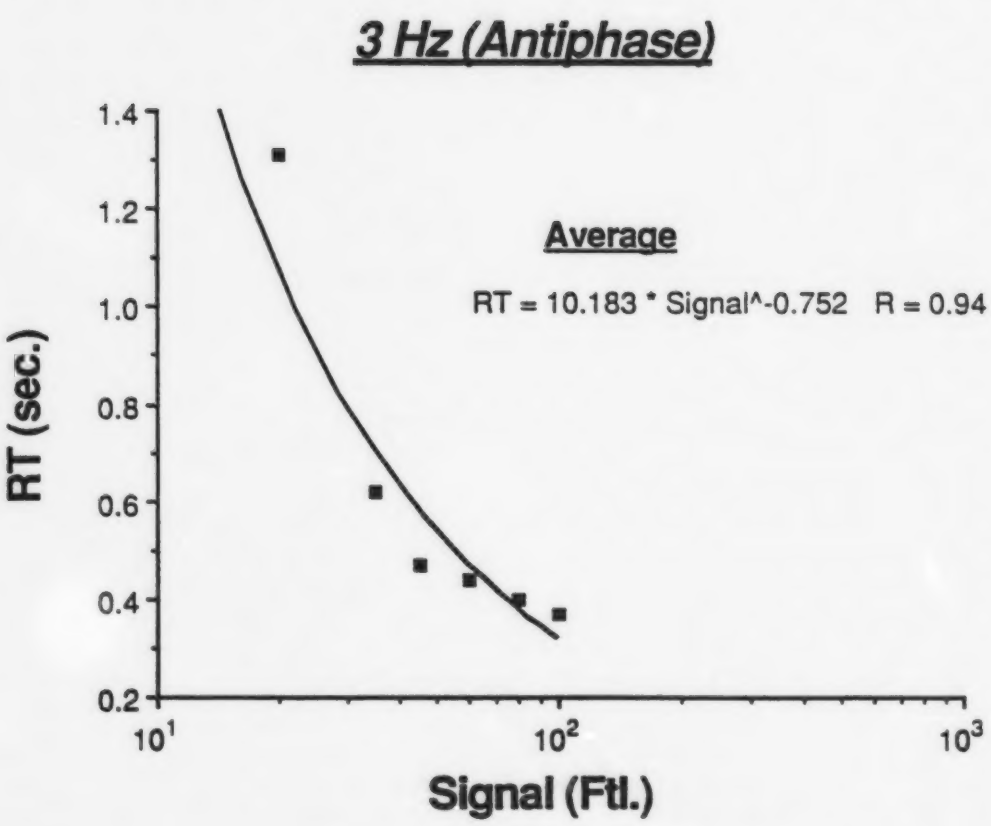

3 Hz (Antiphase)
Average
RT = 10.183 * Signal^-0.752 R = 0.94
RT (sec.)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10^1
10^2
10^3
Signal (Ftl.)

Fig. 5c

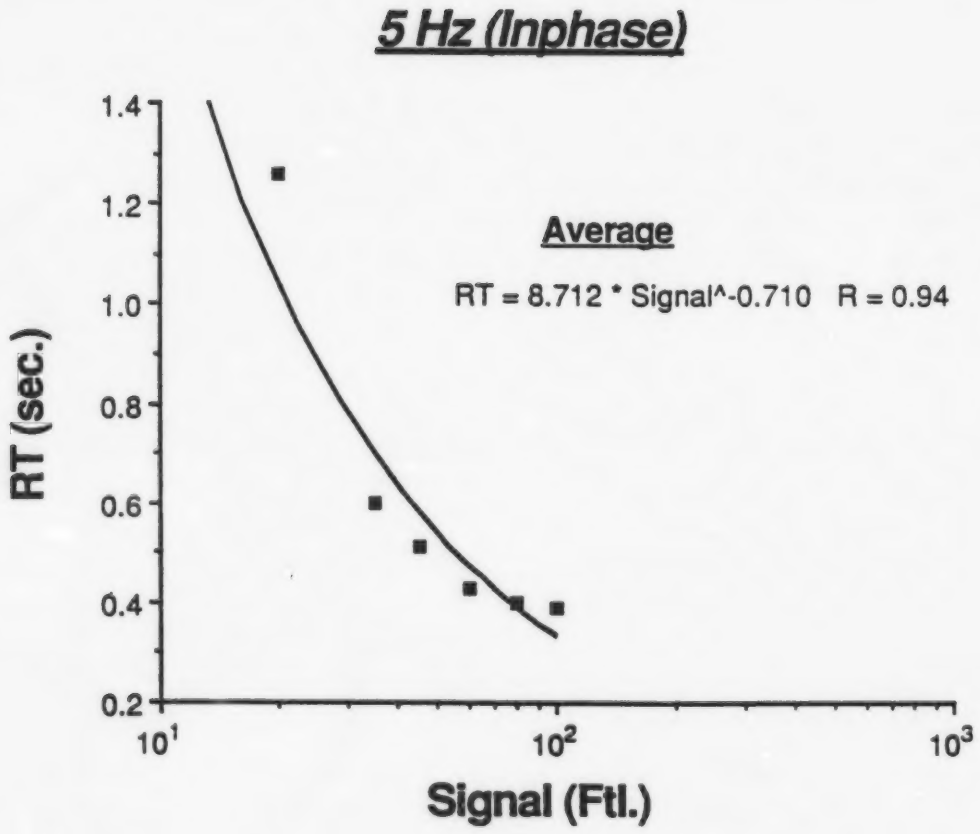

5 Hz (Inphase)
Average
RT = 8.712 * Signal^-0.710 R = 0.94
RT (sec.)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10^1
10^2
10^3
Signal (Ftl.)

Fig. 5d

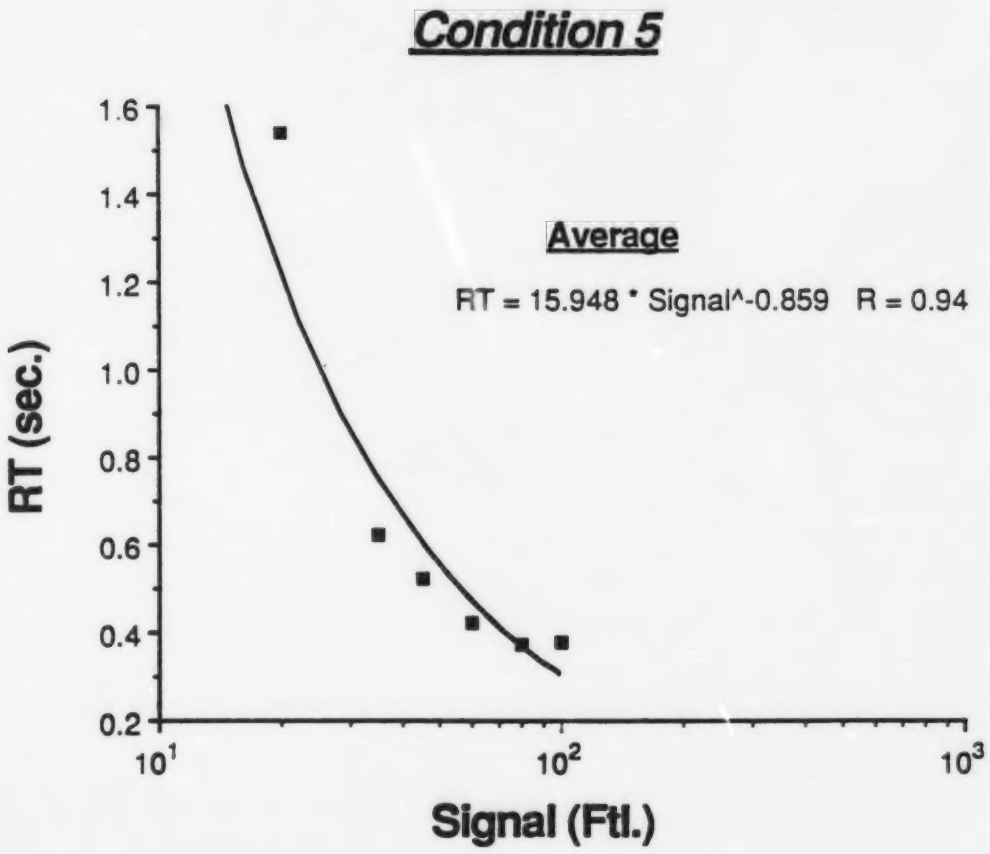

Condition 5
Average
RT = 15.948 * Signal^-0.859 R = 0.94
RT (sec.)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10^1
10^2
10^3
Signal (Ftl.)

Fig. 5e

Discussion

The results of experiment 2 show that, at least in the confines of the laboratory simulation reported here, there is little to choose between the various signal temporal profiles with respect to visual sensitivity. All five conditions were seen and responded to rapidly by the twenty-five observers. Differences that were noted can be attributed to the effect of random onset of the phase cycle of the signals during the experiment. After the variable waiting period following the auditory warning in each trial the test visual signal was turned on at a random position in its temporal profile (at the same time as the reaction time clock) For a stimulus with a duty cycle of 50% this means that, on average, on one half the trials the visual signal would be synchronized with time zero on the reaction time clock in its 'off' phase. During these trials the reaction times will be necessarily longer than on trials where the signal is in the 'on' phase at time zero. This is a reasonable approximation to real world conditions as the probability of any given visual encounter with an activated railway warning signal would be random with respect to signal phase. Thus, all of the signals presented and evaluated here are about equal in providing rapid, simple reaction time responses by observers viewing the driving scene.

Simple reaction time measures are believed to reflect the minimum cumulative times necessary for a signal to be registered in the brain and for the brain to program and execute a simple motor response, such as a button press. Rather than validly reflecting driving behaviour, simple reaction time measures are limited in that they are more of a concession to the technological limits of experimental procedures than to imaginative ones. To the extent that any reaction time measure cannot be shown to relate directly to the task of driving--except, possibly, during the task of driving--these results can only show the way to further research and development work. It is our opinion that the nature of this further research should be as directly related to real world driving conditions as possible.

Bibliography

Baker, C.A., Morris, D.F. and Steedman, W.C., Target Recognition on Complex Displays ***Human Factors***, 1960, pp. 51-61.

Bennett, C.A, Winterstein, S.H. and Kent, R.E, Image quality and target recognition ***Human Factors***, 1967, pp. 5-32.

K. R. Boff, L. Kaufman and J.P. Thomas (eds.) ***Handbook of Perception and Human Performance Volume 1: Sensory Processes and Perception*** Toronto: John Wiley and Sons, 1986.

Brignano, M. and McCullough, M., ***The Search For Safety: A History of Railroad Signals and the People Who Made Them*** Pittsburgh, American Switch and Signal Division, American Standard, Inc., 1981.

Brown, J.L., Time required or detection of acuity targets following exposure to short adapting flashes ***J. Eng. Psychol., 3,***1964 , pp.53-71.

Conners, M.M., Conspicuity target lights: the influence of flash rate and brightness ***N.A.S.A. Technical Note, TND-7961***, 1975.

Crawford, A. The perception of light signals: the effect of mixing flashing and steady irrelevant lights ***Ergonomics, 5,*** 1962, pp. 417-428.

Crawford, A. The perception of light signals: the effect of mixing flashing and steady irrelevant lights Ergonomics, 6, 1963, pp. 287-294.

Crumley, L.M. and Atkinson, W. ***Human engineering investigation of the exterior lighting of naval aircraft. Part 1. A study of the effect of flash rate and on/off ratio on the detectability of flashing lights.*** U.S. Department of the Navy, Bureau of Aeronautics, Nav. Air Mat. Center, U.S. Naval Base, Philadelphia, Pennsylvania, Sept. 23, 1954.

Gerathewohl, S. Conspicuity of flashing light signals of different frequency and duration ***J. Exp. Psychol., 48, (4)***, 1954, pp.247-251.

Gerathewohl, S. Conspicuity of flashing light signals: effects of variation among frequency, duration and contrast of the signals. ***J. Opt. Soc. Am., 47,*** 1957, pp. 27-29.

Heathington, K.W. Fambro, D.B. and Rochesile, R.W., Evaluation of six active warning devices for use at railroad highway grade crossings. ***Transportation Research Record, 956,*** Transportation Research Board, National Research Council, 1984, pp. 1-29.

Hopkins, J.B. and Holmstrom, F.R. Toward more effective grade crossing flashing lights ***Transportation Research Record, 562,*** Transportation Research Board, National Research Council, 1976, pp. 1-14.

International Symposium on the Perception and Application of Flashing Lights, Imperial College, London, Toronto: The University of Toronto Press, 1971.

Kishto, B.N. ***Photometric Evaluation of Flashing Light Sources in Relation to Their Conspicuity,*** Ph.D. Thesis, University of London, 1968.

Leibowitz, H.W., Owens, D.A. and Post, R.B. ***Nighttime driving and visual degredation*** Paper presented at the Society of Automotive Engineers (SAE) International Congress and Exposition, Detroit, Michigan, February 22, 1982. (SAE Technical Paper Series, 820414).

Morrisey, J., ***The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossings.*** Technical Report, Input Output Computer Services, Waltham, MA., 1980.

Seigel, A.I and Crain, K., Experimental investigations of cautionary signal presentations, ***Ergonomics, 3(4),*** 1960, pp. 339-356.

Taylor, M.M. and Creelman, C.D. PEST: Efficient Estimates on Probability Functions ***J. Acoust. Soc. Am. 41,(4),*** 1967, pp. 782-787.

U.S. Department of Transportation, Federal Railroad Administration, Office of Safety, ***Rail-Highway Crossing Safety Report***, July, 1985.

Wallace, R.S. and Associates, ***A review of highway/railway grade crossing protection technology research*** Technical Report prepared for Construction Division, Engineering Branch, Railway Transport Committee, Canadian Transportation Commission, July, 1985.

Watson, A.B. , Temporal Sensitivity in: K. R. Boff, L. Kaufman and J.P. Thomas (eds.) ***Handbook of Perception and Human Performance Volume 1: Sensory Processes and Perception*** Toronto: John Wiley and Sons, 1986. pp.6-1,6-43.

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
DEC 13 1988
Transport Canada / Transports Canada